Estimates of Atlantic salmon smolt production in the Western Brook system, Newfoundland

J. P. Dietrich, R. A. Cunjak, V. Bujold and C. C. Mullins

Science, Oceans and Environment Branch
Newfoundland and Labrador Region
1 Regent Square
Corner Brook, NL
A2H 7K6

2004

Canadian Technical Report of
Fisheries and Aquatic Sciences 2556

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

105-01746/

Canadian Technical Report of
Fisheries and Aquatic Sciences 2556

2004

ESTIMATES OF ATLANTIC SALMON SMOLT PRODUCTION IN THE WESTERN BROOK SYSTEM, NEWFOUNDLAND

by

J. P. Dietrich[1], R. A. Cunjak[2], V. Bujold[3] and C. C. Mullins[4]

Science, Oceans and Environment Branch
Newfoundland and Labrador Region
1 Regent Square
Corner Brook, NF
A2H 7K6

[1] Glenora Fisheries Station, Ministry of Natural Resources, Picton, ON K0K 2T0
[2] Canadian Rivers Institute, University of New Brunswick, Fredericton, NB E3B 6E1
[3] Société de faune et des parcs du Québec, Charlesbourg, QC, Canada
[4] Science, Oceans and Environment Branch, Department of Fisheries and Oceans, Corner Brook, NF A2H 7K6

© Her Majesty the Queen in Right of Canada, 2004.
Cat. No. Fs 97-6/0000E ISSN 0706-6457

Correct citation for this publication:

Dietrich, J. P., Cunjak, R. A., Bujold, V., and Mullins, C. C. 2004. Estimates of Atlantic salmon smolt production in the Western brook system, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 2556: vi +32 p.

TABLE OF CONTENTS

PAGE

ABSTRACT AND RÉSUMÉ iv

LIST OF TABLES v

LIST OF FIGURES v

LIST OF APPENDICES vi

INTRODUCTION 1

METHODS 3

RESULTS 10

DISCUSSION 19

ACKNOWLEDGEMENTS 23

REFERENCES 23

APPENDICES 28

ABSTRACT

The production of Atlantic salmon smolts in the Western Brook system in Gros Morne National Park, Newfoundland was estimated by electrofishing, enumeration at a fish weir, and by mark-recapture techniques over three years. Parr densities for the two tributaries of this system were not significantly different within the same year. However, smolt production was greater in Western Brook than in Stag Brook due to the greater area of suitable rearing habitat; 165 770 m^2 (Hickey 1983) and 82 334 m^2 respectively. No significant difference in parr densities were noticed between years sampled for the same tributary. Estimates of smolt production (1998 – 2000) in the Western Brook system indicated 7 500 – 11 000 smolts produced in one migratory season. The contribution of the fjord lake, Western Brook Pond, to the overall smolt production of the system may be as great as 75%.

RÉSUMÉ

La production de saumonneaux dans le système de Western Brook au Parc National de Gros Morne, Terre-Neuve, a été estimée par pêche électrique, dénombrement à une barrière de comptage et capture-marquage-recapture pendant 3 ans. Les densités de tacons dans les deux tributaires de ce système n'étaient pas significativement différentes pour une même année. Toutefois, la production de saumonneaux était plus importante dans Western Brook comparativement à Stag Brook à cause de la plus grande superficie d'habitat d'élevage de bonne qualité qu'on y retrouve; 165 770 m2 (Hickey 1983) et 82 334 m2 respectivement. Aucune différence significative n'a été démontrée au niveau des densités de tacons entre les années pour un même tributaire. Les estimations de production de saumonneaux (1998-2000) pour le système de Western Brook indiquait qu'entre 7500 et 11 000 saumonneaux étaient produits annuellement. La contribution de Western Brook pond à la productivité de saumonneaux totale du sytème pourrait être aussi élevée que 75 %.

LIST OF TABLES

PAGE

Table 1: Estimated Atlantic salmon smolt production derived from parr densities estimated from electrofishing in Stag Brook and Western Brook from 1998 – 2000. 19

Table 2: Estimates of yearly smolt production created by electrofishing, enumeration and mark-recapture data for Stag Brook, Western Brook Pond, Western Brook, and the system as a whole. 22

LIST OF FIGURES

PAGE

Figure 1: Map showing the Western Brook Pond river system and the location of fyke trap sampling sites, fish-counting fence, and electrofishing sites for 1999 – 2000. 12

Figure 2: Yearly changes in the density (± 1 SD) of Atlantic salmon parr at electrofished sites in Stag Brook and Western Brook. Western Brook was not sampled in 2000 (see text). 17

Figure 3: Yearly changes in the age distribution of Atlantic salmon parr at electrofished sites in Stag Brook and Western Brook with mean fork-length (± 1 SD) by age. 18

Figure 4: Daily counts of Atlantic salmon smolts captured
in a fish counting fence at the mouth Western Brook in 1999.
Daily mean water temperatures are also shown. 21

Figure 5: Daily counts of Atlantic salmon smolts captured
emigrating from (A) Stag Brook and (B) Western Brook Pond
and daily mean water temperatures, 2000. The 10 °C horizontal
line is provided for reference. 25

LIST OF APPENDICES

PAGE

Table A: Description of electrofishing sites sampled in
Stag Brook and Western Brook in 1998 and 1999. 35

Table B: Mean length of adult Atlantic salmon
collected at the upstream fish counting fence in Western Brook
in 1998. Sex was attributed on external phenotypic
characteristics. Stage determination is based on fork-length (cm);
grilse < 63 cm, multi-sea-winter (msw) ≥ 63 cm. 36

Table C: Daily counts, average fork-length, mean age of
Atlantic salmon smolts during operation of the fish
downstream counting fence in Western Book in 1999.
Average fork-length and age are based on a sub-sample of ten
individuals per day. Water benchmarks and average temperatures
are also included. ** Note – increases in water benchmark reflect
a reduction in water level.....37

INTRODUCTION

A key aspect for the management of Atlantic salmon populations is the estimation of emigrating smolts in a river system (Chadwick 1985, Dempson & Stansbury, 1991). Smolts are the last stage in the life cycle of Atlantic salmon that can be censused before fishing mortality occurs. Quantifying changes in smolt abundance and age composition can indicate stock problems requiring management attention, and can be a good indicator of enhanced production due to management (Power 1985).

Atlantic salmon smolt production has been estimated using a variety of approaches. Estimates of standing parr density for a river system have been used to predict the number of smolts to be produced the following year. This method is based on the area of habitat that is available to rear parr. However, this method often is accompanied by large confidence limits resulting in both over- and under-estimations of smolt production (Baglinière et al. 1993, Chadwick and Green 1985).

Total counts or complete census sampling has also been used to estimate Atlantic salmon smolt production. A complete enumeration of the smolts caught exiting a system or a tributary is strongly dependent on the efficiency of the sampling gear, most often a fish-counting fence or fish-way (Saunders and Allen. 1967, Chadwick 1981, Chadwick and Green 1985, Baglinière et al. 1993, Cunjak and Therrien 1998). Counting smolts at traps is considered the most accurate method for determining their abundance (Power 1985). However, traps work best in rivers that are small and/or have relatively low discharge variability. In this situation, efficiencies are high and smolt mortalities are minimal (Chadwick 1985). In larger river systems that have high fluctuations in discharge, obtaining a complete count may not be feasible.

An alternate method of estimating smolt production is by the enumeration of adults. Fish-counting fences and fish ways have been used to enumerate the number of adults returning to a river to spawn. Chadwick and Green (1985) used counts of adults to back-calculate smolt production for Western Arm Brook. Previous studies have quantified survival of Atlantic salmon at sea from smolt to adult stages (Saunders et al. 1967, Hansen 1988). Applying a smolt-adult survival estimate to the number of adults that did return can yield an estimate of smolt production for the previous year.

In situations where total counts (adults or smolts) are not feasible, mark-recapture estimates of salmon smolt abundance have been employed. Many estimates have been based on the single census Petersen formula (Ricker 1975). Assumptions associated with such an estimate are: (1) the population is closed (i.e., additions or losses to the population are negligible during the time of study); (2) fish do not lose there marks; (3) fish are correctly identified as marked or unmarked; (4) marking does not affect the catchability of the fish; and (5) marked and unmarked smolts mix randomly in the population (Ricker 1975, Dempson and Stansbury 1991). However, this estimator may not be appropriate when applied to migrating populations, especially if the assumptions of constant probability of capture, closed population, and random mixing of marked and unmarked individuals are not met (Seber 1982). Rather, previous studies have employed a maximum likelihood estimate (Darroch 1961) for stratified populations (Dempson and Stansbury 1991, Schwarz and Dempson 1994, Schwarz and Taylor 1997). This type of estimate takes into account differences in the probability of capture/recapture during stratified sampling occasions. Estimation using this type of technique requires a large number of smolts to be marked over the stratified time period. A large number of individuals must also be recaptured during each sampling occasion. The Petersen formula may be used, by default, in situations of low numbers (Schwarz and Dempson 1994).

The potential freshwater production of Atlantic salmon smolts has historically been attributed to the amount of fluvial, rearing habitat available to parr (Elson 1975). However, previous studies have shown that, in Newfoundland, juvenile Atlantic salmon rear extensively in lacustrine habitat and, therefore, these habitats need also to be considered when estimating smolt production (Pepper 1976, Pepper et al. 1985, Chadwick and Green 1985, Hutchings 1986, Ryan 1986, O'Connell et al. 1989).

Smolt production in lakes has been difficult to measure. Chadwick and Green (1985) used a combination of a total census of emigrating smolts as well as electrofishing density estimates of fluvial parr to estimate that 67 % of smolts were produced in lacustrine habitats of Western Arm Brook. Mark-recapture estimates have also been used (Ryan, 1986), as well as censussing smolts emigrating from a lake (O'Connell and Ash 1989). Dempson et al. (1996) compared empirical and back-calculated growth of

lacustrine versus fluvial reared Atlantic salmon parr, and concluded that as many as 75 % of the juveniles had used lakes for rearing, further indicating the importance of lakes to smolt production.

The purpose of this study was to provide an estimate of Atlantic smolt production for the Western Brook system, Gros Morne National Park, Newfoundland, based on: 1) standing parr densities, 2) back-calculation from adult counts, 3) direct enumeration, and 4) mark-recapture data. Information pertaining to Atlantic salmon smolt production for this catchment is scarce. Dependable estimates of smolt production would be invaluable in understanding salmon population dynamics in Gros Morne National Park and their comparability to other systems with large lacustrine production. Then this knowledge can be used in the management of a recreational fishery and/or development of a conservation strategy. An estimate of the specific contribution to smolt production from Western Brook Pond, a large fjord lake in the system, is discussed.

METHODS

STUDY AREA

The Western Brook system is located in Gros Morne National Park, Newfoundland (49° 44' N, 57° 46' W) and has a catchment area of 171.2 km^2. Western Brook Pond is an ultraoligotrophic fjord lake that was separated from the ocean after the retreat of glacial ice and isostatic rebound (Kerekes 1994). Steep igneous rock faces that reach elevations of 600 m contain the narrow eastern end of the lake. The western end of the lake widens as relatively flat, low-lying lands surround it. The lake has a surface area of 22.8 km^2, a mean depth of 72.5 m, a maximum depth of 165 m, and a turnover rate of > 15 years (Kerekes 1994). The lake receives drainage from more than 20 streams; all but one (Stag Brook) cascade off the steep cliffs of the fjord. The lake has been described as extremely low in productivity, as demonstrated by a very high oxygen concentration throughout the water column (Kerekes 1994).

Stag Brook, located at the southwestern end of the lake (Figure 1) is the largest tributary entering the lake. It is approximately 8 km in length, with an average width of

9 m. Stag Brook has a substrate consisting of gravel, cobble and large boulders (at higher gradients). The estimated instantaneous discharge during average summer flows was 1.36 m^3/s. Stag Brook has been identified as an important spawning and nursery habitat for Atlantic salmon and other salmonid species that inhabit the system (Ball 1991, Anions 1994).

Western Brook Pond is drained by Western Brook at its northwestern end. Western Brook flows for approximately 9 km before emptying into the Gulf of St. Lawrence (Figure 1). It has a mean width of 35 m and has substrate ranging from bedrock and boulders to gravel and cobble. Steadies along the length of this brook have substrate of sand and mud with scattered boulders. The estimated instantaneous discharge during average summer flow was 7.48 m^3/s; as measured at the widening of the river near the first steady (lentic environment) downstream of Western Brook Pond (Figure 1). Depth and velocity were measured at one meter intervals across the width of the river allowing for calculation of total mean discharge.

Other fish species present in the Western Book Pond river system are threespine stickleback (*Gasterosteus aculeatus* (Linnaeus)), American eel (*Anguilla rostrata* (Lesuer)), alewife (*Alosa pseudoharengus* (Wilson)), brook charr (*Salvelinus fontinalis* (Mitchill)), rainbow smelt (*Osmerus mordax* (Mitchill)), and Arctic charr (*Salvelinus alpinus* (Linnaeus)).

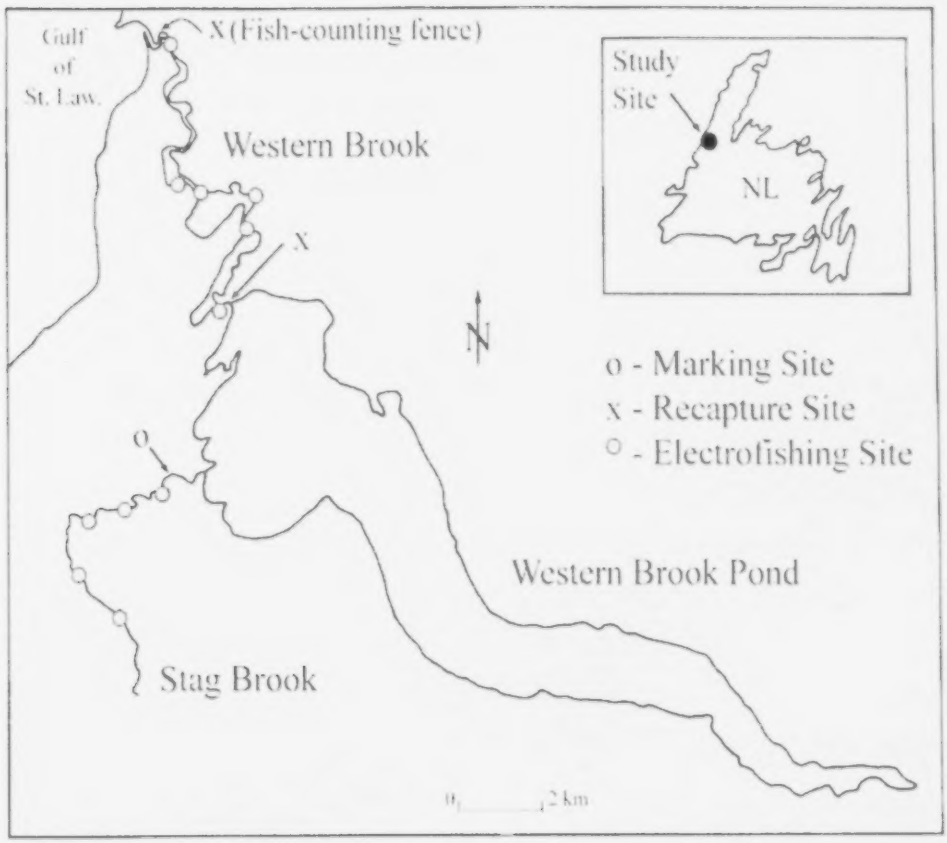

Figure 1: Map showing the Western Brook river system and the locations of fyke trap marking and recapture sampling sites, fish-counting fence, and electrofishing sites for 1999 – 2000.

1. ELECTROFISHING

Electrofishing surveys were conducted during summer in 1998, 1999 and 2000 to estimate the density of parr in the fluvial portions of the system. Five sites were located in Stag Brook and six in Western Brook (Figure 1).

The sampling sites represented the habitat types typically found in the river; these included riffles, runs, and flats. Sampling was carried out during the last week of July and the first week of August in all years as the low water conditions needed for sampling persisted over this time period (Appendix A). Sites were blocked off with barrier nets of

0.5 cm mesh and the area corralled by the nets was measured. The enclosed sections were electrofished 3 to 4 times (sweeps). After each sweep, captured salmon parr were anesthetized (using a 40 ppm clove oil/ethanol bath as per Anderson et al. 1997), measured for length and weight, sampled for scales, and retained in a live-box until the completion of sampling for that site.

Stag Brook was surveyed in 1999 for the occurrence of riffles, runs, flats and pools from its headwaters to its mouth. Measurements of river length and width were taken at each of these habitat types for subsequent calculation of the total area of suitable rearing habitat available, from 1998-2000, for juvenile Atlantic salmon.

Western Brook was previously surveyed in July and August of 1983 for the occurrence of particular habitat types by Hickey (1983). Measurements of habitat length and width were carried out manually (with a tape measure) and with aerial photographs for calculation of the area of suitable parr rearing habitat for the brook. The area of suitable parr rearing habitat reported by Hickey (1983) was used in the present study to estimate the total abundance of parr in Western Brook in 1998 and 1999. Elevated water levels precluded electrofishing in 2000 and, therefore, parr densities for the lower portion of the river system (i.e. Western Brook) were not made.

All scales were aged to determine the age distribution of parr captured in each portion of the river. This distribution was then used to predict the number of parr age ≥ 2 that contributed to smolt production the following year; the vast majority of smolts exiting this system are age 3 (Dietrich, 2001). A survival rate of 30 % from summer parr to spring smolts (Cunjak and Therrien 1998) was used to estimate smolt production. Mean standing parr densities were averaged over habitat types (i.e. riffle, run, and flat) and a single extrapolation was made to estimate the total density for the river using measurements of total available parr rearing habitat.

2. COUNTING FENCE OPERATIONS

In 1999, a fish-counting fence was constructed just below the head of tide in Western Brook (Figure 1). This fish counting fence was constructed of aluminum conduit spaced 6 mm apart and had an upstream adult trap and a downstream smolt trap (Anderson and McDonald 1978). It was operational from June 3 to September 8.

Adult Atlantic salmon captured in the upstream fish trap were counted, identified as grilse or multi-winter sea adult, and sexed by external examination. All adults were also measured for length and weight, and sampled for scales (Appendix B).

Using a smolt-adult survival rate of 4-6 % that coincided with survival rates observed at Western Arm Brook during 1997 to 1999 (C. Mullins pers. comm. D. F. O., Newfoundland), an estimate of the previous year's smolt production for the entire system was calculated from the count of adult grilse spawners caught at the counting fence.

The fish-counting fence was intended to give a total count of smolts exiting the Western Brook system in 1999. Smolts captured in the trap were observed for any marks administered at upstream marking sites. A sub-sample of ten smolts per day was anesthetized and measured for length and weight (Appendix C). The efficiency of the smolt fence with 6 mm spacing between the conduits was tested. A fyke net was placed approximately 500 m upstream from the fish-counting fence and smolts captured were given upper caudal fin clips (UCFC). The efficiency of the smolt-counting trap (at the fence) was then applied to the number of Atlantic salmon smolts caught exiting the system in 1999 to estimate the total number of smolts emigrating for that year.

3. MARK – RECAPTURE ESTIMATE

Two fyke traps (18 mm mesh size) were set in Stag Brook on May 30 until July 27, 2000 (Figure 1). The traps were fitted with wooden live-boxes at their cod end to reduce mortality due to capture. All captured smolts were anesthetized using a 40 ppm clove oil bath and measured for fork-length and weight.

A Panjet dental inoculator was used to administer Alcian Blue tattoos to the ventral body surface, just anterior to the pelvic girdle (Hart & Pitcher 1969, Moffett et al. 1997). This location was chosen due to its lack of pigmentation that made the mark easily distinguishable. Individually numbered Carlin tags were also used to mark migrating smolts. These green plastic tags were attached just anterior of the dorsal fin with double polyethylene monofilament thread. All individuals were further marked with an anal fin clip (AFC) to create a check on tag or tattoo loss. Marked smolts were held for 24 hours to detect if mortalities may have resulted from marking.

Approximately half of the smolts were then given Panjet tattoos and the other half was Carlin tagged. Marking occurred throughout the duration of the smolt run in Stag Brook.

Five fyke traps were situated approximately 440 m downstream from Western Brook Pond between June 14 and July 28, 2000 (recapture site A). This site was approximately 5 km downstream from where smolts were marked in Stag Brook (Figure 1). Velocity measurements were taken on July 15, 2000. The instantaneous discharge calculated from these measurements was 7.48 m^3/s. The five fyke traps at this site sampled 4.31 m^3/s or 57.6 % of the total stream flow. A sixth fyke trap (recapture site B) was used to capture and mark smolts (with upper caudal fin clips) approximately 300 m upstream from the location of recapture site A. Smolts marked at the recapture site B were used to calculate capture efficiency of the five fyke traps farther downstream (recapture site A), and estimate the total number of smolts emigrating from Western Brook Pond (Figure 1). The smolts captured at all fyke traps were checked carefully for marks administered in Stag Brook. Stag Brook recaptures were anesthetized and re-measured for length and weight. By subtracting the estimate of smolt produced in Stag Brook for the same year, an estimate of the smolt production of the lake was reached.

STATISTICAL ANALYSES

Densities of salmon parr were calculated using catch-depletion data and the removal method for population estimation (Zippin 1956, Seber 1982). This analysis gave maximum-likelihood estimates of population size ($\tilde{N}$) and the percentage of the population captured after 3 – 4 sweeps for a site. Inter-annual comparisons of parr density in both Stag Brook and Western Brook were tested using a one-way ANOVA followed by pairwise difference testing. Student's *t*-tests were preformed to compare parr densities between the two brooks for 1998 and 1999.

The mean fork-length (cm) of Panjet tattooed and Carlin tagged smolts that were held for 24 hrs was compared by student's *t*-test. The same test was used to analyze differences in fork-length (cm) of tattooed versus tagged smolts that were recaptured in Western Brook. Chi-square analysis was used to compare the frequency of individuals

that were recaptured at Western Brook for each of the two mark types administered in Stag Brook.

The mark-recapture data were used in a single census Petersen method to estimate the population of smolts exiting the system in 2000.

The Petersen estimate is calculated in the following manner (Chapman 1951).

$$\tilde{N} = [(M + 1)(C+1) \Big/ (R + 1)] - 1$$

where $\tilde{N}$ = size of population at time of marking

M = number of fish marked

C = catch or sample taken for census

R = number of recaptures in the sample

The variance estimate for $\tilde{N}$ (Seber 1970) is:

$$V(\tilde{N}) = [(M + 1)(C + 1)(M - R)(C - R)] \Big/ [(R + 1)^2(R + 2)]$$

The 95 % confidence intervals for the population size (Lohr 1999) were calculated using:

$$\tilde{N} \pm 1.96 \sqrt{V(\tilde{N})}$$

RESULTS

1. ESTIMATE OF SMOLT PRODUCTION IN STAG BROOK TRIBUTARY AND WESTERN BROOK BASED ON AGE 2+ PARR DENSITY

Although a slight decrease in mean total parr density (number of fish per 100 m^2) in Stag Brook from 1998 – 2000 occurred, this difference was not significant ($P > 0.05$). This difference could be related to earlier run timing in 1999 (i.e. lower numbers in Stag in 1999 but higher numbers in Western Brook). Similarly, there was no significant change in the mean parr density of Western Brook between 1998 and 1999. The comparison of total parr density between tributaries within the same year showed no significant difference
($P > 0.05$)(Figure 2).

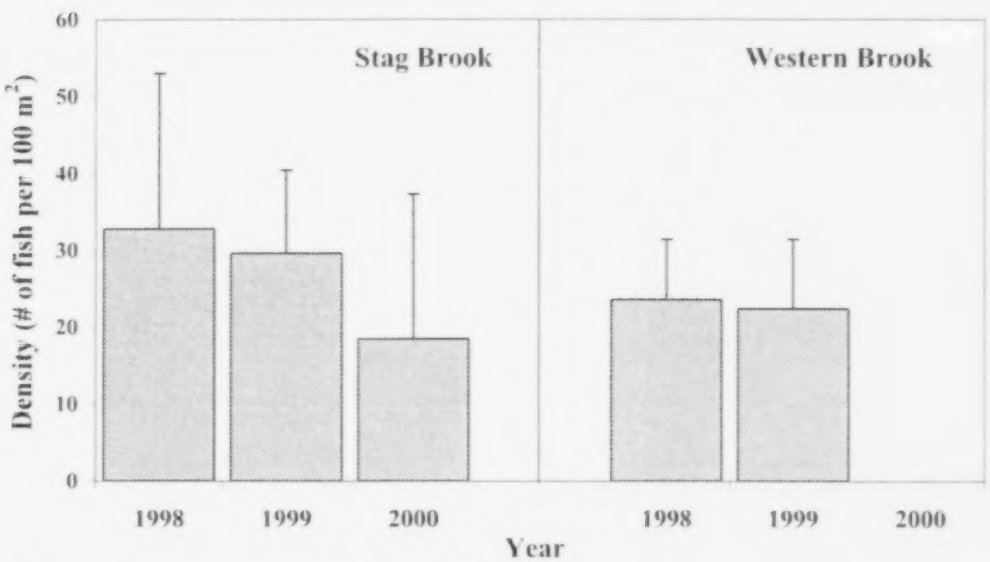

Figure 2: Yearly changes in the density (± 1 SD) of Atlantic salmon parr at electrofished sites in Stag Brook and Western Brook. Western Brook was not sampled in 2000 (see text).

The calculated mean parr density in Stag Brook in 1998 was 32.81 ± 17.67 (95% C. I.) parr/100 m^2 (Table 1). Total parr rearing habitat in Stag Brook was estimated to be 82 334 m^2. Therefore the total number of parr in Stag Brook in 1998 was estimated to be 27 014 parr ± 14 548 (95% C. I.). 33 % of parr captured during electrofishing were age 2 or 3 (Figure 3). Applying this percentage to the estimated total number of parr in Stag Brook in 1998 yields an estimate of 8 915 parr ≥ age 2. Assuming a survival of 30 % for Atlantic salmon from the parr to smolt stage (Cunjak and Therrien 1998), an estimated 2 674 ± 1 440 (95% C. I.) smolts were predicted from Stag Brook in 1999 (Table 1).

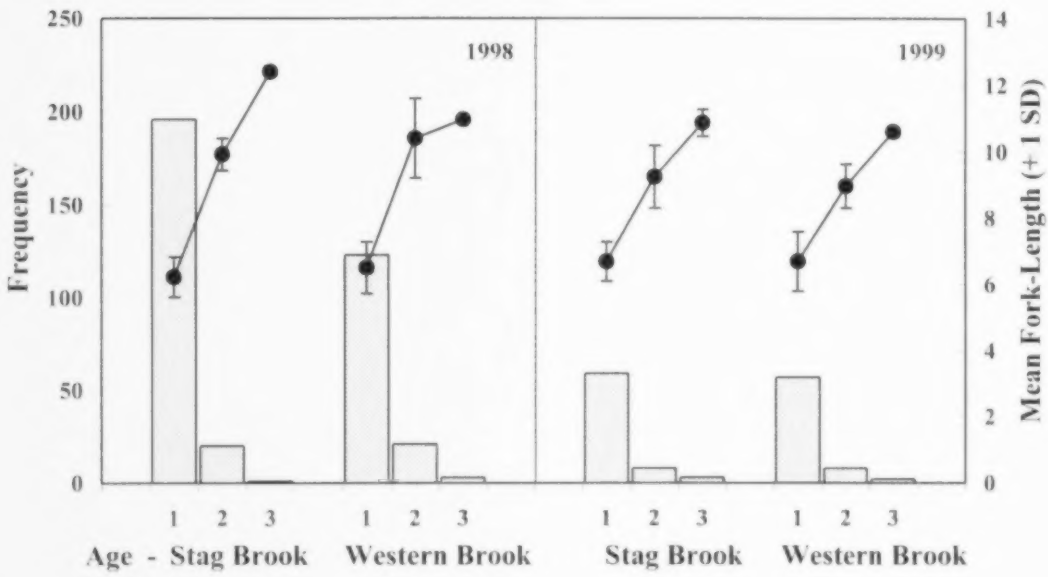

Figure 3: Yearly changes in the age distribution of Atlantic salmon parr at electrofished sites in Stag Brook and Western Brook with mean fork-length (± 1 SD) by age.

Table 1: Estimated Atlantic salmon smolt production derived from parr densities estimated from electrofishing in Stag Brook and Western Brook from 1998 – 2000.

Year (n)	Tributary	Density (# fish/100 m^2) (± 95% C. I.)	Estimate of Parr Pop. (N) (± 95% C. I.)	Estimate of Age ≥ 2 Parr in Population (± 95% C. I.)	Estimate of Smolt Production (year n + 1) (± 95% C. I.)
1998	Stag Brook	32.81 ± 17.67	27014 ± 14548	8915 ± 4801	2674 ± 1440
	Western Brook	23.59 ± 6.87	39105 ± 11388	12905 ± 3758	3871 ± 1127
1999	Stag Brook	29.63 ± 9.49	24396 ± 7813	8051 ± 2578	2415 ± 774
	Western Brook	22.35 ± 7.98	37066 ± 13224	12232 ± 4364	3670 ± 1309
2000	Stag Brook	18.27 ± 16.57	15182 ± 13642	5010 ± 4502	1503 ± 1351
	Western Brook	n/a	n/a	n/a	n/a
Means	Stag Brook	26.96 ± 8.54	22192 ± 7033	7325 ± 2321	2198 ± 696
	Western Brook	22.98 ± 1.21	38094 ± 2011	12571 ± 663	3771 ± 199

The same calculations were carried out for Stag Brook in 1999 and 2000. The predicted smolt production in Stag Brook was greatest for 1999 compared with 2000 and 2001. The estimate of smolt production for 2001 was the lowest of all three years sampled (Table 1). The estimated smolt production for this tributary ranged from 1 503 – 2 674, with the average being 2 198 ± 696 (95% C. I.) smolts.

In Western Brook, the estimated the area of suitable parr rearing habitat was 165 770 m^2 (Hickey 1983) approximately twice that of Stag Brook. The parr density in Western Brook from electrofishing data in 1998 was 23.59 parr / 100 m^2 (Table 1). The proportion of parr age ≥ 2 in Western Brook was 33 %, the same as in Stag Brook, and the survival from parr to smolt was again assumed to be 30 % (Cunjak and Therrien 1998). Therefore, the predicted smolt production for Western Brook in 1999 was 3 670 ± 1 309 (95% C. I.)(Table 1). Predicted smolt production for 2000 was 3 668, and the mean for the two years was 3 771 ± 199 (95% C. I.)(Table 1).

Using this method of estimation the sub-catchments were predicted an average range of 5 074 to 6 864 smolts per year from 1999 – 2001. However, this estimate does

not take into consideration the number of smolts that may be produced from parr rearing in Western Brook Pond and other lentic habitats (steadies) of Western Brook.

2a. ESTIMATE OF SMOLT PRODUCTION IN WESTERN BROOK SYSTEM BASED ON NUMBER OF MIGRATING ADULT SALMON IN THE PREVIOUS YEAR

The fish counting fence was operational from June 17 – October 9, 1998. The run began on June 19 and ended on October 5 with the peak in upstream migration occurring during the first two weeks of July. The number of one sea-winter Atlantic salmon (grilse) captured moving upstream at the Western Brook fish fence in 1998 was 223 (mean fork-length = 52.8 cm) and 80 multi-sea winter adults (mean fork-length 72.6 cm) were counted (Bujold 2003). Using a 4-6 % smolt-adult survival coefficient (C. Mullins, pers. comm., D. F. O. Newfoundland) then the total number of smolts emigrating out of the system in 1997 was between 3 716 and 5 575
(Table 2).

In 1999, the fish counting fence was operational from June 9 to September 8. Migrating Atlantic salmon were captured on the first day of sampling (June 9) indicating that the run may have commenced prior to this date. The peak of upstream movement occurred during the first two weeks of July (1 to 15) and the run ended on September 1. The number of Atlantic salmon grilse captured moving upstream at the Western Brook fish fence in 1999 was 328 (mean fork-length = 55.6 cm) and 58 multi-sea winter adults (mean fork-length = 73.8 cm) were counted (Bujold 2003). Using the same 4-6 % smolt to adult survival estimate, then the total number of smolts emigrating out of the system in 1998 was between 5 466 – 8 200 smolts (Table 2).

2b. ESTIMATE OF TOTAL SMOLT PRODUCTION IN WESTERN BROOK BASED ON SMOLTS COUNTED AT THE RIVER MOUTH

The number of smolts counted leaving the system at the mouth of Western Brook in 1999 was 1707. However, the efficiency of the smolt fence was estimated at 20 %. As a result, the total number of smolts leaving the system in 1999 was estimated to be 8 535 smolts (Table 2). Trapping began on June 3 and the peak in smolt emigration occurred

on June 25, the run was finished by July 30 (Figure 4). The mean fork-length of smolts caught exiting the system was 15.9 ± 1.8 cm. A sub-sample of 404 smolts showed that approximately 71% were age 3; 27% were age 4; and only 2% were aged 2 years.

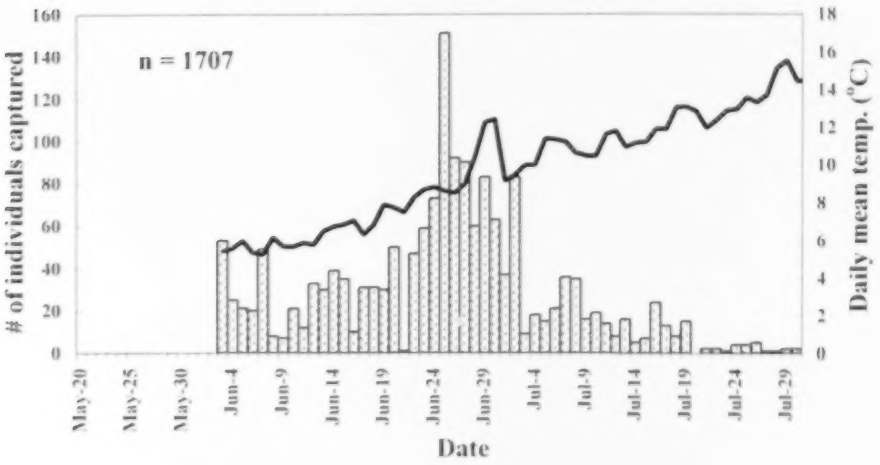

Figure 4: Daily counts of Atlantic salmon smolts captured in a fish counting fence at the mouth Western Brook in 1999. Daily mean water temperatures are also shown.

Table 2: Estimates of yearly smolt production created by electrofishing, enumeration and mark-recapture data for Stag Brook, Western Brook Pond, Western Brook, and the system as a whole.

Smolt Year	Technique of Estimation	Water Body	Estimated Smolt Production
1997	Back calculation (fish fence 1998 - adults)	Total system	3 716 – 5 575
1998	Back calculation (fish fence 1999 - adults)	Total system	5 466 – 8 200
1999	Enumeration (fish fence 1999 - smolts)	Total system	8 535
	Electrofishing	Stag Brook	2 674 ± 1440
		Western Brook	3 871 ± 1127
	Enumeration	Western Brook Pond	2 490
2000		Total System	11 647
	Electrofishing (parr density 1999)	Stag Brook	2 415 ± 774
		Western Brook	3 670 ± 1309
	Enumeration (fyke traps 2000)	Western Brook Pond	5 562
	Mark-Recapture (Petersen formula)	Stag Brook + Western Brook Pond	14 892 ± 5 081

2c. ESTIMATE OF SMOLT PRODUCTION IN WESTERN BROOK POND

The estimate of Atlantic salmon smolts leaving the system in 1999 was 8 535 (Table 2). By subtracting the predicted smolt production of both Stag Brook tributary and Western Brook for 1999, which was estimated using the parr densities in these two tributaries in 1998 (Table 1), the production of smolts in the lake can be isolated:

8 535 (total) – 2 674 (Stag Brook) – 3 371 (Western Brook) = 2 490 lake smolts (Table 2).

This was approximately half the smolt production estimated from the lake in 2000. 916 smolts were captured emigrating from Western Brook Pond in 2000. The efficiency of capture was 12 % (5 smolts recaptured out of 42 marked). Therefore the total number of smolts that may have migrated past this site in 2000 was 7 633. However, this number includes smolts produced in Stag Brook that migrate though the lake in the same year (Dietrich 2001). If the estimated number of smolts produced in Stag Brook in 2000 (using the electrofishing data for 1999, Table 1) is subtracted from the above estimate, smolt production from the lake in 2000 was:

7 633 – 2 071 (Stag Brook) = 5 562 smolts

Therefore, the total production of smolts for the entire river system using the above estimates was:

2 071 (Stag Brook) + 5 562 (Western Brook Pond) + 3 668 (Western Brook) = 11 301 smolts (Table 2).

3. MARK-RECAPTURE ESTIMATE OF SMOLT PRODUCTION

In 2000, sampling began on May 26 in Stag Brook, and the first smolt was caught on May 28. Two peaks in smolt migration occurred when the water temperature was near 8-9 °C (Figure 5). The first occurred on June 1 and the second on June 7. A third peak in migration occurred on June 18 when the water temperature reached 14 °C. 470 smolts were captured and marked in Stag Brook in 2000 (Figure 5).

352 Atlantic salmon smolts were marked with Panjet or Carlin tag and held for 24 hr. The size of fish was not a deciding factor on the type of mark used. The mean fork-length of smolts marked with Carlin tags and held for 24 hrs was 12.7 ± 1.4 cm (mean ± 1 S.D.), while the mean fork-length of tattooed smolts was significantly smaller ($P <$

0.05) at 12.0 ± 1.2 cm. The total number of mortalities after handling and marking was 9 smolts (2.6 %). The number of smolts that were marked with Carlin tags was 167; 6 (3.6 %) of these died, all before being placed in the live trap. The number of smolts marked with Panjet tattoo was 185; 3 (1.6 %) of these died, all after spending some time in the live trap. There was no significant difference in mortality rate between the two marking techniques.

The first smolt was caught on June 17. The peak in migration out of Western Brook Pond occurred from July 3 – 7 when the water temperature reached 11 °C. Sampling ended on July 28 by which time 916 smolts were captured (Figure 5).

In total, 470 migrating Atlantic salmon smolts were caught and marked in Stag Brook. The total number of recaptures was 28, giving an overall recapture rate of 6.0 %. Of the 183 smolts given Panjet tattoos, 11 were recaptured at the Western Brook Pond recapture site for a recapture percentage of 6.0 %. 17 of the 287 individuals given Carlin tags were recovered for a recapture percentage of 5.9 %, which was not significantly difference than the rate for tattooed smolts.

The total number of smolts marked in Stag Brook was 470. The total number of captures at the outflow of Western Brook Pond was 916. The total number of recaptures was 28. The Petersen method yielded an estimate of 14 892 ± 5 081 (95 % confidence interval) of smolts from both Stag Brook and the lake. This estimate was higher than the parr density estimate for 2000, and higher than smolt estimates in previous years for the upper portion of the system (Table 2).

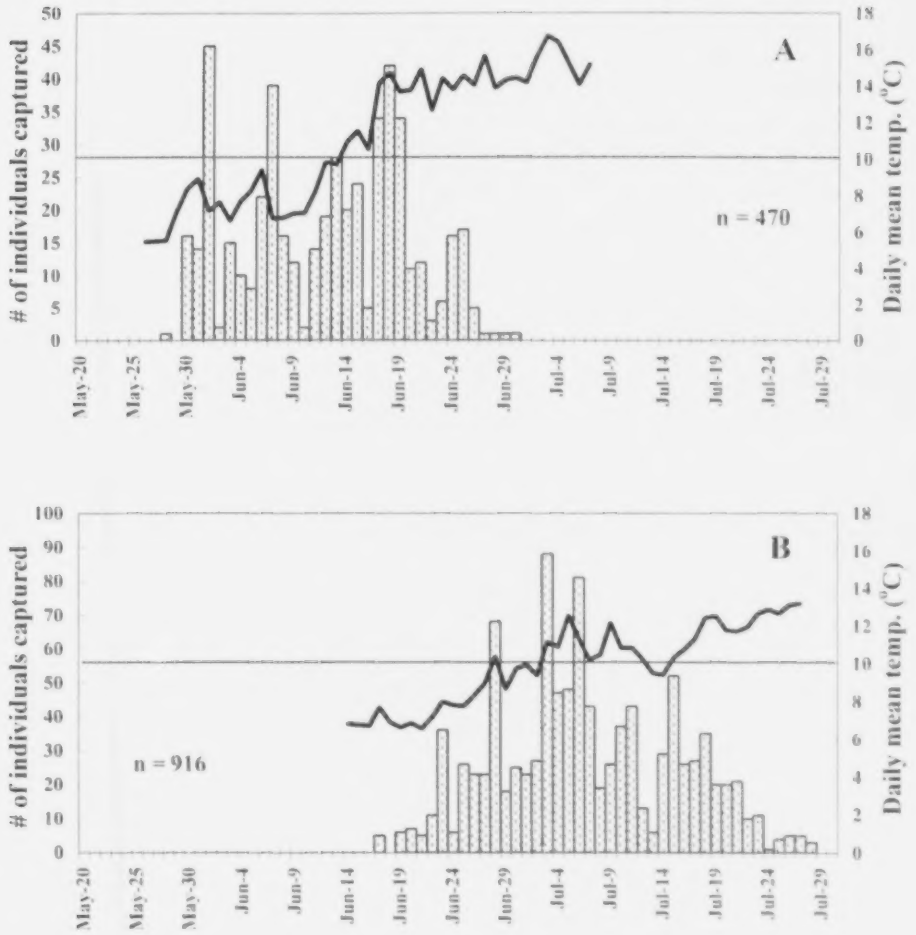

Figure 5: Daily counts of Atlantic salmon smolts captured emigrating from (A) Stag Brook and (B) Western Brook Pond and daily mean water temperatures, 2000. The 10 °C horizontal line is provided for reference.

DISCUSSION

The parr densities estimated from electrofishing surveys 1998 – 2000, indicated that the density of parr in both Stag Brook and Western Brook were stable over the three years sampled. The higher parr densities and smolt production estimates in Stag Brook compared with Western Brook are in contrast to Hickey (1983), who reported little potential rearing habitat in this tributary. However, our results coincide with the opinion of Ball (1991) that Stag Brook was responsible for a significant amount of juvenile production in the river system. Further, previous studies (Porter et al. 1974, Hickey 1983, Ball 1991) did not provide data on parr densities and do not take into account the contribution of Western Brook Pond or the three steadies of Western Brook to total smolt production.

Lentic habitats (i.e., steadies) in the system were not sampled in the present study. Possible use of these steadies by Atlantic salmon parr may represent an underestimation of smolt production from the Western Brook system (Pepper 1976, Pepper et al. 1985, Chadwick and Green 1985, Hutchings 1986, Ryan 1986, O'Connell and Ash. 1989). Other sources of error in our estimates may be because of a limited number of sampling sites, and inaccuracies in the measurement of suitable parr habitat. However, when compared with estimates derived from other sampling techniques, the predicted production of smolts in Stag Brook and Western Brook from standing parr densities seems realistic. Furthermore, by supplementing the estimated fluvial smolt production with an estimate of production from Western Brook Pond (using enumeration and trap efficiency data) a more complete estimate of production for the system was achieved.

Estimations of smolt production were approximately equal for 1997-1999. However, the estimate of smolt production for 2000 was greater than in the previous three years. Smolt production for 1997 may be an underestimate since some adult salmon were observed squeezing between the conduit of the fence (1998) and it is unknown how many individuals were not enumerated. However, counts of grilse at the fence in 1999 were almost twice that in 1998. The estimate of smolt production in 1998 is assumed to be reliable as the efficiency of the fish counting fence in 1999 was greatly improved. Smolt-adult survival was not determined for the Western Brook system salmon population. Rather, a survival rate of 4 -6 % from nearby Western Arm Brook

(Mullins and Caines 2000) was used in the present study. Western Arm Brook is located approximately 180 km north of Western Brook and was considered representative of Northern Peninsula rivers. The rate of smolt-adult survival used in this study seems appropriate because the estimate of smolt production by direct enumeration of smolts in 1999 was quite close. The efficiency of the fish-counting fence for smolt capture in 1999 was 20 %, which is low. Smolts were observed swimming between conduits that were spaced only 6 mm apart, something not reported previously. The predicted number of smolts exiting the system in 1999 by direct enumeration is also similar to the estimate of smolt production for the same year using parr densities in 1998. Consequently, the estimate of efficiency for the fish fence is reasonable. Previous attempts at smolt enumeration (1984 to 1990) for the system were generally unsuccessful due to improper location of the fish fence and a series of high water events (Ball 1991, Anions 1994).

Although annual smolt production may be river-specific, the estimated increase in smolt production from 1997 to 2000 in the Western Brook system is in contrast to the finding of Mullins and Caines (2000), who reported a decline in smolt production in each successive year in Western Arm Brook. In 1997, the number of smolts leaving Western Arm Brook was 23 845, and by 2000 only 12 691 smolts were produced (Mullins and Caines 2000) by the 149 km^2 system (Porter et al. 1974). Smolt production for the Western Brook system in 2000 may have been overestimated due to the predicted number of smolts produced in the pond. The number of smolts produced by Western Brook Pond was estimated through enumeration and testing the efficiency of the traps used in enumeration. The efficiency of these traps was tested later in the smolt run (July 6-22) when the river discharge was relatively low and the fish may have been "trap shy". The efficiency of these traps may have been greater earlier in the run and therefore the estimate of smolt production by Western Brook Pond may have been under estimated. The estimate of lake production, using the estimated parr density of Stag Brook and Western Brook (1998) subtracted from the total production of the system in 1999 (as predicted by direct enumeration), indicates approximately 3 000 less smolts produced by the lake in 1999 than in 2000. This further indicates that the 2000 prediction of smolt production by the lake may have been inflated.

Despite possible inaccuracies with the estimate of smolts produced by Western Brook Pond, it is clear that this lake contributes significantly to the production of smolts in the Western Brook system. The predicted contribution of Western Brook Pond to total smolt production in the entire system ranged from 30 % in 1999 to as high as 50 % in 2000, which may be an under estimate since sampling at the outflow of the lake was delayed in 2000 by high water events. From the difference between a total census of emigrating smolts and fluvial standing parr density, Chadwick and Green (1985) estimated that 67 % of the smolts produced in Western Arm Brook, Newfoundland, came from lacustrine habitats. Therefore, estimates of lacustrine smolt production for the Western Brook system are realistic. Dempson et al. (1996), through analysis of scale characteristics, estimated that 75 % of parr sampled in the Conne River, Newfoundland, used lakes for rearing. Although confirmation of migration to Western Brook Pond by salmon parr from Stag Brook is not available, the large number of smolts caught exiting the lake in 2000 relative to the number of smolts enumerated exiting the system in 1999 indicates some degree of parr rearing and a substantial contribution to smolt production from the fjord lake.

The mark-recapture estimate was used to quantify production for the upper portion of the system (i.e., Stag Brook and Western Brook Pond). The numbers marked, captured, and recaptured were not sufficient to use stratification estimation techniques (Schwarz and Dempson 1994). As a result, a single-census Petersen estimate was employed by default. The estimated production of the upper part of the Western Brook system using the Petersen estimate was high (14 892 ± 5 081), likely due to the low numbers of smolts tagged and recaptured.

Panjet tattoos were used, with the expectation that they were a less stressful mark for smolts relative to marking by Carlin tag. However, initial mortality was not significantly different between the marking techniques and the similar recapture success of smolts marked by the two methods indicates that the low number of recaptures was not the result of tagging mortality. There were no incidences of tag or mark loss and misidentification was negligible.

When using the Petersen index for research purposes, where the population estimate will be used as a preliminary step to further research, the preferred margin of

error divided by the estimated population size (ME / $\hat{N}$) is $\leq$ 10 %, but, a ME / $\hat{N} \leq$ 50 % is considered acceptable for initial assessments of populations (pers. comm., C. Schwarz via C. Mullins, D. F. O.). Our estimate of smolt production for the Western Brook system was considered a preliminary survey as little previous work had been carried out on the subject. The total smolt estimate generated using the mark-recapture data from this study was 14 892, with a margin of error equal to 5 081.

Less than half the expected marked smolts were recaptured. To reach a confidence interval of 10 % with the number of individuals marked and captured, 180 recaptures were needed. It seems most likely that a lack of recapture success occurred in this study. The assumptions of constant probability of capture and random mixing of marked and unmarked individuals may have been compromised since the distance traveled between the marking site and recapture site was through a lake. Reductions in migratory speed (Dietrich, 2001) may have caused inaccuracies in the Petersen estimate. As a result, the estimates generated by electrofishing parr density and enumeration of adults and smolts are likely more reliable than the mark-recapture technique.

Due to the error associated with each type of estimating technique, a reliable single estimate of smolts produced by the system was not possible. However, the range in smolt production created by most of the estimation techniques provides reasonable bounds for smolt production in the Western Brook system. The contribution by the upper part of the system (Stag Brook and Western Brook Pond) may be as high as 75 % of total smolt production and the contribution of the pond itself may range from 30 to 50 %.

The results of this study are a successful step in the monitoring of this system, and it presents baseline information on the juvenile salmon population therein. Recent proposals to increase the amount of tourism and research on Western Brook Pond may have impact on the Atlantic salmon community there. This study provides a reference point for the future monitoring of the effects of increased anthropogenic disturbance.

ACKNOWLEDGEMENTS

We wish to thank the administration and staff of Gros Morne National Park, most especially Dr. Stephen Flemming and Chris McCarthy. Brian Dempson provided helpful comments during the design of this study. Field assistance was provided by Dan Cartwright, David Courtemanche, Kirk Pilgrim, Cory Kennedy, and Ryan Delong. Further expertise was provided by Pat Caines and Don Caines of the Department of Fisheries and Oceans. We thank B. Dempson and K. Clark for greatly improving this report.

REFERENCES

Anderson, T. C., and McDonald, B. P. 1978. A portable weir for counting migrating fishes in rivers. Fish. Mar. Serv. Tech. Rep. 733: 13p.

Anderson, W. G., McKinley, R. S., and Colavecchia, M. 1997. The use of clove oilas an anesthetic for rainbow trout and its effects on swimming performance. N. Am. J. Fish. Manage. 17: 301 – 307.

Anions, M. F. E. 1994. The freshwater fish of Gros Morne National Park, resource description and analysis. Gros Morne National Park. 69 p.

Ball, B. 1991. Salmonid management study, Gros Morne National Park, 1987 –1990 field program activity report. Gros Morne National Park. 35 p.

Baglinière, J. C., Maisse, G., and Nihouarn, A. 1993. Comparison of two methods of estimating Atlantic salmon (*Salmo salar*) wild smolt production. *In* Production of juvenile Atlantic salmon, (*Salmo salar*) in natural water. (Gibson, R.J. and. Cutting, R.E., eds), pp. 189 – 201. Can. J. Fish. Aquat. Sci. 118.

Bujold, V. 2003. Egg-to-fry survival models and drifting fry biology of wild Atlanticsalmon (*Salmo salar* L.). Thesis (M.Sc.) University of New Brunswick, Fredericton, NB, Canada. 139 p.

Chadwick, E. M. P. 1981. Biological characteristics of Atlantic salmon smolts in Western Arm Brook, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1024.

Chadwick, E. M. P. 1985. Fundamental research problems in the management of Atlantic salmon, *Salmo salar* L., in Atlantic Canada. J. Fish Biol. 27 (Suppl. A): 9 – 25.

Chadwick, E. M. P. and Green, J. M. 1985. Atlantic salmon (*Salmo salar* L.) production in a largely lacustrine Newfoundland watershed. Verh. Internat. Verein. Limnol. 22: 2509 – 2515.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. University of California Publications in Statistics 1: 131 – 160.

Cunjak, R. A. and Therrien, J. 1998. Inter-stage survival of wild juvenile Atlantic salmon, *Salmo salar* L. Fish. Manage. Ecol. 5: 209-223

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48: 241 – 261.

Dempson, J. B. and Stansbury, D. E. 1991. Using partial counting fences and a two-sample stratified design for mark-recapture estimation of an Atlantic salmon smolt population. N. Am. J. Fish. Manage. 11: 27 – 37.

Dempson, J. B., O'Connell, M. F., and Shears, M. 1996. Relative production of Atlantic salmon from fluvial and lacustrine habitats estimated from analyses of scale characteristics. J. Fish Biol. 48: 329-341

Dietrich, J. P. 2001. The behaviour, survival and production of Atlantic salmon (*Salmo salar* L.) smolts in the Western Brook system. Thesis (M.Sc.) University of New Brunswick, Fredericton, NB, Canada. 128 p.

Elson, P. F. 1975. Atlantic salmon rivers smolt production and optimal spawning an overview of natural production. International Atlantic Salmon Foundation Special Publication Series 6: 96 – 119.

Hansen, L. P. 1988. Effects of Carlin tagging and fin clipping on the survival of Atlantic salmon (*Salmo salar* L.) released as smolts. Aquaculture 70: 391 – 394.

Hart, P. J. B. and Pitcher, T. J. 1969. Field trials of fish marking using a jet inoculator. J. Fish Biol. 1: 383 – 385.

Hickey, T. E. 1983. Preliminary assessment of Atlantic salmon habitat potential of selected streams in Gros Morne National Park, 1983. Hardy Associates (1978) Ltd. Report for Parks Canada. 19p., 17 tables, appendices, 13 photos, 21 maps.

Hutchings, J. A. 1986. Lakeward migrations by juvenile Atlantic salmon, *Salmo salar*. Can. J. Fish. Aquat. Sci. 43: 732 – 741.

Kerekes, J. J. 1994. Western Brook Pond. Pp. 284 – 293. *In*: Allan, R. J. et al. (*eds.*). The book of Canadian Lakes. Canadian Association on the Water Quality, Monograph No. 3. Canada Centre for Inland Waters, Burlington, Ont. 598p.

Lohr, S. A. 1999. Sampling design and analysis. California: Brooks/Cole

Moffett, I. J. J., Crozier, W. W., and Kennedy, G. J. A. 1997. A comparison of five external marks for Atlantic salmon, *Salmo salar* L. Fish. Manage. Ecol. 4: 49 – 53.

Mullins, C.C., and Caines, D. 2000. Status of Atlantic salmon (*Salmo salar* L.) stocks of Lomond River, Torrent River and Western Arm Brook, Newfoundland, 1999. DFO Can. Stock Assess. Sec. Res. Doc. 2000/38, 40p.

O'Connell, M. F., and Ash, E. G. M. 1989. Atlantic salmon (*Salmo salar*) smolt production in a Newfoundland river system characterized by lacustrine habitat. Int. Revue ges. Hydrobio. 74: 73 – 82.

Pepper, V. A. 1976. Lacustrine nursery areas for Atlantic salmon in insular Newfoundland. Fish. Mar. Serv. Tech. Rep. 671: 61 pp.

Pepper, V. A., Oliver, N. P. and Blundon, R. 1985. Evaluation of an experiment in lacustrine rearing of juvenile anadromous Atlantic salmon. N. Am. J. Fish. Manage. 5: 507 – 525.

Porter, T. R., Riche, L. G., and Traverse, G. R. 1974. Catalogue of rivers in insular Newfoundland. Department of Environment, Fisheries and Marine Service, Resource Development Branch Internal Report Series No. NEW/D-74-2, Volume C. x + 364p.

Power, G. 1985. Estimating and understanding smolt output from Atlantic salmon rivers. In 1985 Northeast Atlantic salmon workshop. pp. 108 – 124 Atlantic Salmon Federation Montreal, and New Brunswick Wildlife Federation, Moncton.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191.

Ryan, P. M. (1986). Lake use by wild anadromous Atlantic salmon, *Salmo salar*, as an index of subsequent adult abundance. Can. J. Fish. Aquat. Sci. 43: 2 – 11.

Saunders, R. L. and Allen, K. R. 1967. Effects of tagging and of fin-clipping on the survival and growth of Atlantic salmon between smolt and adult stages. J. Fish. Res. Board Can. 24: 2595 – 2611.

Schwarz, C. J. and Dempson, J. B. 1994. Mark-recapture estimation of a salmon smolt population. Biometrics 50: 98 – 108.

Schwarz, C. J. and Taylor, C. G. 1997. Use of the stratified-Petersen estimator in fisheries management, estimating the number of pink salmon (*Onchorynchus gorbuscha*) spawners in the Fraser River. Can. J. Fish. Aquat. Sci. 55: 281 – 296.

Seber, G. A. F. 1970. The effects of trap response on tag-recapture estimates. Biometrics 26: 13 – 22.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. New York, N.Y.: MacMillan Publishing Co. Inc.

Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. Biometrics 12: 163 – 189.

APPENDIX A

Table A: Description of electrofishing sites sampled in Stag Brook and Western Brook in 1998 and 1999.

Water Body	Site	Date	Habitat	Substrate	Average Temp. (°C)	Length (m)	Mean Width (m)	Area (m^2)
Stag Brook	1	98/07/22	riffle	boulder and rock	17.2	54.6	10.4	565.1
Stag Brook	2	98/07/23	run	boulder and rock	18.1	21.5	10.3	221.5
Stag Brook	3	98/07/27	run/flat	cobble and gravel	19.1	12.5	6.3	78.8
Stag Brook	4	98/07/28	riffle	cobble and gravel	18.2	8.1	9.9	80.2
Stag Brook	5	98/07/28	riffle	rock, cobble and pebble	18.2	15.1	10.8	163.5
Western Brook	6	98/07/29	run	boulder, gravel and sand	19.4	10.0	13.6	136.0
Western Brook	7	98/07/29	riffle	boulder, cobble and sand	19.4	9.9	9.6	95.0
Western Brook	8	98/07/31	run	boulder and cobble	19.2	15.8	8.3	131.1
Western Brook	9	98/07/31	riffle	boulder and cobble	19.2	8.6	20.0	171.0
Western Brook	10	98/07/04	run/flat	boulder and gravel	19.6	11.1	8.5	94.6
Western Brook	11	98/07/04	riffle	rock, cobble and gravel	19.6	10.9	8.6	93.3
Stag Brook	1	99/07/21	riffle	boulder and rock	17.3	19.0	10.8	205.2
Stag Brook	2	99/07/22	run	boulder and rock	16.9	11.5	10.9	125.4
Stag Brook	3	99/07/22	run/flat	cobble and gravel	16.9	9.5	7.0	66.0
Stag Brook	4	99/07/26	riffle	cobble and gravel	18.2	12.8	10.4	132.6
Stag Brook	5	99/07/27	riffle	rock, cobble and pebble	18.0	7.5	7.9	58.5
Western Brook	6	99/07/27	run	boulder, gravel and sand	13.7	8.9	11.2	99.7
Western Brook	7	99/07/28	riffle	boulder, cobble and sand	15.1	7.2	10.6	76.6
Western Brook	8	99/07/28	run	boulder and cobble	15.1	4.7	10.5	49.1
Western Brook	9	99/07/29	riffle	boulder and cobble	15.5	4.9	13.0	63.8
Western Brook	10	99/07/29	run/flat	boulder and gravel	15.5	8.1	8.3	67.2
Western Brook	11	99/07/30	riffle	rock, cobble and gravel	14.4	4.3	8.1	34.8

APPENDIX B

Table B: Mean length of adult Atlantic salmon collected at the upstream fish counting fence in Western Brook in 1998. Sex was attributed on external phenotypic characteristics. Stage determination is based on fork-length (cm); grilse < 63 cm, multi-sea-winter (msw) ≥ 63 cm.

Year	External sex	Stage	Count	Mean FL (cm)	StdDev	Min. FL (cm)	Max. FL (cm)
1998	female	grilse	99	52.26	2.94	46.60	62.60
1998	female	msw	51	71.38	8.79	50.10	92.50
1998	female total		150	58.76	10.68	46.60	92.50
1998	male	grilse	114	52.82	3.24	46.40	63.00
1998	male	msw	39	70.81	7.06	56.90	90.90
1998	male total		153	57.44	9.08	46.40	90.90
Total			**303**	**58.10**	**9.91**	**46.40**	**92.50**
1999	female	grilse	241	55.09	2.96	46.80	63.00
1999	female	msw	51	74.49	6.03	63.40	88.60
1999	female total		292	58.50	8.26	46.80	88.60
1999	male	grilse	85	56.18	2.41	50.00	62.70
1999	male	msw	9	73.00	5.55	66.90	82.20
1999	male total		94	57.80	5.74	50.00	82.20
Total			**386**	**58.33**	**7.72**	**46.80**	**88.60**
Grand Total			**689**	**58.23**	**8.75**	**46.40**	**92.50**

APPENDIX C

Table C: Daily counts, average fork-length, mean age of Atlantic salmon smolts during operation of the downstream fish counting fence in Western Book in 1999. Average fork-length and age are based on a sub-sample of ten individuals per day. Water benchmarks and average temperatures are also included. ** Note – increases in water benchmark reflect a reduction in water level.

Date	Count	Avg. FL (cm)	SE	Avg. Age (yrs)	SE	Water Benchmark (cm)	Avg. Temp (^{0}C)
20-May	-	-	-	-	-	-	-
21-May	-	-	-	-	-	-	-
22-May	-	-	-	-	-	-	-
23-May	-	-	-	-	-	-	-
24-May	-	-	-	-	-	-	-
25-May	-	-	-	-	-	-	-
26-May	-	-	-	-	-	-	-
27-May	-	-	-	-	-	-	-
28-May	-	-	-	-	-	-	-
29-May	-	-	-	-	-	-	-
30-May	-	-	-	-	-	-	-
31-May	-	-	-	-	-	-	-
1-Jun	-	-	-	-	-	-	-
2-Jun	-	-	-	-	-	-	-
3-Jun	53	14.3	0.12	3.4	0.07	87.3	5.42
4-Jun	25	14.5	0.20	3.2	0.06	88.0	5.55
5-Jun	21	13.7	0.15	3.2	0.07	-	5.95
6-Jun	20	13.3	0.14	3.4	0.02	84.0	5.33
7-Jun	49	13.7	0.16	3.4	0.05	86.3	5.24
8-Jun	8	13.5	0.29	3.5	0	88.0	6.12
9-Jun	7	14.7	0.14	3.7	0.06	91.0	5.67
10-Jun	21	15.1	0.17	3.8	0.07	-	5.65
11-Jun	12	15.0	0.14	3.6	0.04	93.7	5.85
12-Jun	33	14.8	0.13	3.6	0.05	96.4	5.75
13-Jun	30	14.9	0.25	3.7	0.04	95.0	6.48
14-Jun	39	15.7	0.28	3.4	0.04	90.5	6.71
15-Jun	35	14.2	0.14	3.4	0.06	96.4	6.81
16-Jun	10	-	-	-	-	95.0	7.03
17-Jun	31	16.5	0.14	3.8	0.04	90.5	6.30
18-Jun	31	-	-	-	-	92.5	6.81

19-Jun	30	15.3	0.54	4.0	0.14	-	7.87
20-Jun	50	16.0	0.17	3.5	0.06	96.2	7.72
21-Jun	1	-	-	-	-	100.0	7.48
22-Jun	47	17.5	0.17	4.1	0.04	102.6	8.27
23-Jun	59	15.5	0.14	3.5	0.03	103.9	8.68
24-Jun	73	16.0	0.12	3.6	0.03	105.4	8.80
25-Jun	151	17.1	0.18	3.5	0.05	.	8.60
26-Jun	92	17.5	0.14	4.0	0.04	108.8	8.49
27-Jun	90	16.7	0.14	3.7	0.06	111.0	8.97
28-Jun	60	17.0	0.13	3.6	0.08	112.2	10.40
29-Jun	83	16.0	0.19	3.4	0.05	112.1	12.27
30-Jun	63	-	-	-	-	113.0	12.41
1-Jul	37	17.6	0.20	3.8	0.05	113.5	9.16
2-Jul	83	17.3	0.14	3.8	0.05	114.5	9.45
3-Jul	9	16.7	0.41	3.7	0.09	112.0	9.97
4-Jul	18	17.2	0.15	3.7	0.06	112.5	9.99
5-Jul	15	16.9	0.12	3.7	0.05	112.8	11.39
6-Jul	21	17.6	0.17	3.7	0.04	112.5	11.35
7-Jul	36	17.0	0.11	3.7	0.05	114.8	11.21
8-Jul	35	17.3	0.11	3.8	0.04	116.0	10.61
9-Jul	16	18.4	0.45	4.2	0.14	115.2	10.45
10-Jul	19	-	-	-	-	115.9	10.45
11-Jul	14	17.1	0.32	3.9	0.11	118.4	11.61
12-Jul	8	18.1	0.23	3.8	0.09	114.8	11.80
13-Jul	16	17.7	0.11	3.9	0.05	-	10.94
14-Jul	5	18.1	0.59	3.8	0.13	117.5	11.17
15-Jul	7	16.3	0.21	3.7	0.07	117.0	11.21
16-Jul	24	17.4	0.15	3.6	0.04	117.2	11.89
17-Jul	13	21.9	0.19	4.1	0.06	-	11.91
18-Jul	8	16.4	0.17	3.8	0.06	120.1	13.05
19-Jul	15	17.8	0.10	3.6	0.02	118.9	13.08
20-Jul	0	20.5	-	4.0	0	120.1	12.83
21-Jul	2	16.2	0.11	3.5	0	1[illegible].2	11.95
22-Jul	2	17.9	0.14	3.7	0.05	120.6	12.37
23-Jul	1	18.6	-	-	-	120.1	12.87
24-Jul	4	15.9	0.14	4.0	0.35	118.0	12.95
25-Jul	4	17.0	0.47	3.8	0.19	115.5	13.57
26-Jul	5	17.5	0.20	3.5	0	114.6	13.33
27-Jul	1	-	-	-	-	115.0	13.71
28-Jul	1	18.2	-	4.5	0	115.5	15.13
29-Jul	2	18.4	1.27	4.0	0.35	115.8	15.55
30-Jul	2	16.5	1.31	3.5	0	117.5	14.45
31-Jul	2	14.9	-	3.5	0	118.3	14.48
1-Aug	6	16.7	0.19	3.5	0	118.9	15.22
2-Aug	5	18.1	0.49	4.1	0.18	119.2	14.88
3-Aug	1	11.9	-	2.5	-	118.9	14.38
4-Aug	4	18.9	0.36	4.3	0.24	119.6	15.27
5-Aug	0	-	-	-	-	121.2	15.54

6-Aug	1	19.4	.	4.5	0	-	16.43
7-Aug	0	-	-	-	-	118.6	16.87
8-Aug	0	-	-	-	-	118.6	14.28
9-Aug	0	-	-	-	-	120.2	15.00
10-Aug	0	-	-	-	-	116.0	13.69
11-Aug	0	-	-	-	-	115.1	13.50
12-Aug	0	-	-	-	-	113.6	13.73
13-Aug	0	-	-	-	-	112.1	14.13
14-Aug	1	18.4	-	-	-	113.1	14.37
15-Aug	7	18.3	0.46	3.9	0.14	94.6	14.18
16-Aug	1	-	-	-	-	81.0	14.67
17-Aug	6	20.4	0.29	4.0	0.09	81.2	14.58
18-Aug	7	20.4	0.43	4.1	0.08	83.0	14.56
19-Aug	5	19.1	0.64	3.5	0.29	81.5	14.73
20-Aug	1	14.7	0.00	2.5	0	70.9	14.67
21-Aug	4	17.5	0.53	3.2	0.14	71.8	14.54
22-Aug	0	-	-	-	-	76.4	14.59
23-Aug	0	-	-	-	-	81.0	14.60
24-Aug	2	21.0	1.45	4.0	3.5	84.2	14.77
25-Aug	1	21.6	0.00	3.5	0	87.7	14.80
26-Aug	1	23.4	0.00	4.5	0	91.6	14.60
27-Aug	0	-	-	-	-	93.6	14.57
28-Aug	2	17.0	1.84	3.0	0.35	96.5	14.75
29-Aug	2	19.1	2.69	3.5	0	98.0	14.98
30-Aug	0	-	-	-	-	97.2	14.88
31-Aug	0	-	-	-	-	-	14.80
1-Sep	0	-	-	-	-	104.0	14.80
2-Sep	0	-	-	-	-	-	14.78
3-Sep	0	-	-	-	-	105.5	14.96
4-Sep	1	-	-	-	-	107.2	14.52
5-Sep	0	-	-	-	-	109.9	14.64
6-Sep	0	-	-	-	-	109.6	14.82
7-Sep	0	-	-	-	-	107.5	14.26
8-Sep	0	-	-	-	-	-	18.35
9-Sep	0	-	-	-	-	-	21.32
10-Sep	0	-	-	-	-	-	20.60
11-Sep	0	-	-	-	-	-	23.01